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CHARACTERISTICS OF THE TURBULENT BOUNDARY LAYER WITH HEAT AND MASS TRANSFER: DATA TABULATION

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CHARACTERISTICS OF THE TURBULENT BOUNDARY LAYER WITH HEAT AND MASS TRANSFER: DATA TABULATION

by

James E. Danberg

ABSTRACT: A tabulation of turbulent boundary layer data obtained under conditions of heat and mass transfer at a Mach number of 6.7 is presented. The report supplements the treatise given in NOLTR 64-99. A brief description of the model and test procedure is included.

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Characteristics of the Turbulent Boundary Layer with Heat and Mass Transfer: Data Tabulation

This report presents the measured and deduced data obtained during an extensive investigation of hypersonic turbulent boundary layers with heat and mass transfer. The work was sponsored by the Bureau of Naval Weapons under Task No. RMGA-42-034/212-1/F009-10-001. It resulted in a Ph.D. thesis by the author submitted to the Catholic University of America. Only summary data were included in the thesis, which was also published as NOLTR 64-99. The present report was compiled after numerous requests for detailed data from other researchers in this field.

The author wishes to acknowledge the efforts of the Aerophysics Division of the U. S. Naval Ordnance Laboratory in preparing the material for publication.

E. F. SCHREITER
Captain, USN
Commander

E. L. Harris

E. L. HARRIS
By direction

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LIST OF SYMBOLS

C_f	skin friction coefficient, $\tau_w/\frac{1}{2}\rho_\delta u_\delta^2$
C_{fo}	skin friction coefficient for zero mass transfer
C_q	mass transfer coefficient, $\rho_w v_w/\rho_\delta u_\delta$
M	local Mach number
M_δ	Mach number at outer edge of boundary layer
P_o	supply air pressure
Re_x	Reynolds number, $\rho_\delta u_\delta x/\mu_\delta$
Re_θ	Reynolds number, $\rho_\delta u_\delta \theta/\mu_\delta$
St	Stanton number
St_o	Stanton number for zero mass transfer
T_o	supply air temperature
T_w	wall surface temperature
T_δ	temperature at outer edge of boundary layer
u	local velocity
u_δ	velocity at outer edge of boundary layer
v_w	velocity component perpendicular to wall at wall surface
x	distance from leading edge of plate in direction of free-stream velocity
δ	total boundary layer thickness
δ^*	displacement thickness
θ	momentum thickness
ϑ	energy thickness
μ_δ	viscosity at outer edge of boundary layer
ρ_w	density at wall condition
ρ_δ	density at outer edge of boundary layer
τ_w	wall shear stress

INTRODUCTION

NOLTR 64-99 (ref. (1)) summarized an extensive program of turbulent boundary layer measurements under conditions of heat and mass transfer at a Mach number of 6.7. That report contained some typical velocity and temperature profiles as well as the correlation of the boundary layer profiles in terms of a number of parameters related to the heat and mass transfer, etc. In order to make that report more generally useful, it has been decided to publish in the present report the tabulated boundary layer data obtained during the course of that project.

The experiments were performed in the U. S. Naval Ordnance Laboratory's Hypersonic Research Tunnel using a Mach number 6.7 uniform flow two-dimensional nozzle with an exit area of about 25 x 25 cm^2. The supply pressure and temperature were held constant during each test at a fixed pressure value between 15 and 38 atmospheres and at a constant supply temperature of 550°K. The control of these conditions limited the average deviation in nozzle temperature to ±1°C and in supply pressure to ±0.1 atmosphere.

The boundary layer measurements were made on a porous flat plate (see figure 1) which spanned the wind tunnel test section with the testing surface in the plane of symmetry of the two-dimensional nozzle. The plate had a sharp leading edge (radius of about .015 mm) and it had a smooth (about 11 microinches) continuous surface. Inserted in the testing surface of the model was a porous plate about 49 cm long, 18 cm wide, and 1.0 cm thick. The porous plate was made of 316 stainless steel powder sintered into compact material with a density of about 43 percent of solid stainless steel. Further details are given in the original report.

In order to make this tabulation of the experimental data more useful and complete, the instrumentation employed and the data reduction techniques are summarized in the following sections.

INSTRUMENTATION AND DATA REDUCTION

Pitot Pressure Probes

The majority of boundary layer Pitot pressure surveys were made using circular stainless steel tubing .559 mm in outside diameter and with an inlet diameter of .254 mm. A few surveys were made using rectangular cross section probes made from crushed tubing. Circular probes were preferred because of the greater ease in determining their position and orientation with respect to the model.

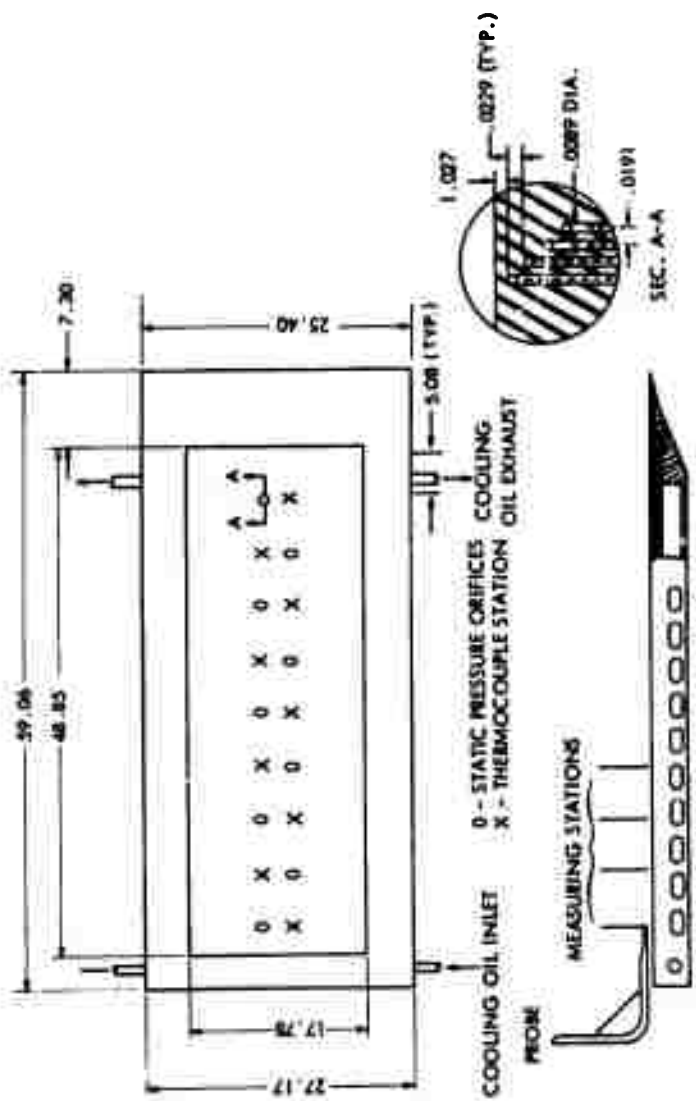

FIG. 1 SKETCH OF MODEL (ALL DIMENSIONS IN CM)

Pressures were measured with transducers with ranges of 0-1 atmosphere or 0-300 mmHg. Transducers and recording systems were calibrated, before and after each survey, against a mercury manometer with ±.1 mm measuring accuracy.

The probes were held in the tunnel by a micrometer-traversing mechanism which allowed positioning of the probe with an accuracy of .025 mm. Each traverse was made from the free stream toward the plate. Wall contact, used to evaluate absolute distances from the wall, was indicated by the completion of an electric circuit.

Pressure Data Reduction

The NACA tables (ref. (2)) were used to compute the Mach number from the measured Pitot pressure and the static pressure which was assumed constant across the boundary layer and equal to the measured wall static pressure. Wall static pressures were measured by orifices in the porous plate surface through which stainless steel tubing (0.635 mm I.D.) was inserted flush with the testing surface. An oil manometer was used to measure the static pressure with an accuracy of ±1 percent.

The surface shear stress was calculated by taking the slope of the Mach number distribution at the wall and multiplying this by the velocity of sound and viscosity of air evaluated at the measured wall temperature. The wall temperature and heat flux were obtained from temperature measurements made with iron-constantan thermocouples imbedded in the porous material at each test station. Four thermocouples were located at each station at various depths from the surface. The thermocouple nearest the surface was 1.27 mm beneath the surface. Together with the known location of the others, extrapolation of the temperature distribution to a surface value was felt to give reliable results.

Temperature Measurements

The equilibrium temperature probe (ref. (3)) was developed to measure the boundary layer temperature profiles for these experiments. It consists of a 10 degree angle cone of platinum supported by a good thermal insulator. The cone is mounted on the traversing mechanism with its axis parallel to the flow direction. A thermocouple measured the temperature of the cone which ideally should equal the adiabatic wall temperature. Sufficient run time was available in the NOL Hypersonic Tunnel to allow the probe to come into thermal equilibrium before each measurement was made. A second thermocouple in the ceramic insulator allowed the measured cone temperature to be corrected for conduction losses. The data were recorded on strip chart recorders which made continuous monitoring of the temperatures possible.

Temperature Probe Data Reduction

A recovery factor for the probe was computed for each survey while the probe was in the free stream where the flow and temperature

conditions were accurately known. It was assumed that the recovery factor remained constant thereafter for that survey. Thus it was possible to calculate the local total temperature in the boundary layer from the cone adiabatic wall temperature measurement, the assumed recovery factor and measured Mach number. Since temperatures were not always measured at the same location as the pressures, an interpolation was made between temperature data points to obtain the temperatures corresponding to the Mach number data points.

Heat transfer rates to the model surface were calculated from the slope of the total temperature distribution interpolated to the surface temperature and the thermal conductivity of air. This procedure supplements the heat transfer obtained from the temperature distribution within the model wall.

In calculating Stanton numbers, the adiabatic wall temperatures are required to obtain the latter for the zero mass transfer cases. It was assumed that the recovery factor equals the Prandtl number raised to the one third power where wall temperature was used to evaluate the Prandtl number. In the mass transfer cases the recovery factor ratios (i.e., recovery factor with mass transfer divided by the zero mass transfer recovery factor) obtained by Leadon and Bartle (ref. (4)) were used.

TEST CONDITIONS

As indicated earlier, the tests were run using a nominal Mach number 6.7 nozzle. However, local Mach numbers at the boundary layer edge were somewhat less because of leading edge shock wave losses and boundary layer flow field interaction; the latter was a significant effect in the mass transfer cases. The supply temperature was held constant at 550°K, while the supply pressure was varied between 15 and 38 atmospheres. Thus, the unit Reynolds number varied from 8 to 19 x 10^6 per meter.

Four locations on the model were investigated: 37.78, 42.86, 47.94, and 53.02 cm from the leading edge. Natural transition was believed to have been completed because a local maximum in the wall temperature was observed at or before 32.7 cm from the leading edge. (Reynolds number = 2.6 x 10^6). Three wall temperature ratios (T_w/T_∞) were investigated which had numerical values that averaged to 4.1, 5.2, and 7.6. The boundary layers were surveyed at zero air injection and at three mass transfer rates which were approximately equal to 0.09, 0.17, and 0.25 percent of free-stream mass flow per unit area except in the high supply pressure cases where the maximum injection rate was about 0.11 percent of the free-stream mass flow.

ARRANGEMENT OF TABLES

The measured and deduced boundary layer data are presented as summary tables containing the detailed profile data. Two summary

tables precede each set of profile data obtained for specific test conditions, i.e., P_o, and T_w/T_δ, and various values of C_q, as shown in the following tabulation.

Table No.	P_o* atm	T_w/T_δ*	C_q*	Profile Data Table Nos.
1 & 2	15	4.1	0	3
			9.09×10^{-4}	through
			17.0×10^{-4}	
			25.0×10^{-4}	23
24 & 25	15	5.2	0	26
			8.77×10^{-4}	through
			17.2×10^{-4}	
			24.6×10^{-4}	42
43 & 44	15	7.6	0	45
			8.68×10^{-4}	through
			16.2×10^{-4}	
			24.4×10^{-4}	52
53 & 54	38	7.6	0	55
			3.7×10^{-4}	through
			7.25×10^{-4}	
			10.13×10^{-4}	58
59 & 60	38	4.1	0	61
			4.12×10^{-4}	through
			8.17×10^{-4}	
			12.1×10^{-4}	67

*The values of P_o, T_w/T_δ, and C_q are average or nominal values for these quantities for the purpose of identifying the tables--the precise values are listed in the tables for each of the surveys carried out.

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(3) Danberg, J. E., "The Equilibrium Temperature Probe: A Device for Measuring Temperatures in Hypersonic Boundary Layers," The Second National Symposium on Hypervelocity Techniques at the University of Denver, Denver, Colorado, 20-21 Mar 1962

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TABLE 1 SUMMARY OF SKIN FRICTION AND HEAT TRANSFER DATA, $T_w/T_\delta = 4.1$

$T_w/T_\delta = 4.1$

RUN	X	M_δ	P_o	$Re_x \times 10^{-6}$	Re_θ	T_w/T_δ	$C_q \times 10^4$	$C_f \times 10^4$	C_f/C_{f_o}	$2C_q/C_{f_o}$	$St \times 10^4$	$\frac{St}{St_o}$
	mm		atm									
						$C_q = 0$		$T_w/T_\delta = 4.48$				
1	377.8	6.60	15.18	3.255	1947	4.475	0	14.58	1.000	0	4.97	1.000
2	428.6	6.55	15.15	3.533	2374	4.480	0	13.85	1.000	0	4.97	1.000
3	479.4	6.54	15.15	3.880	2527	4.479	0	14.46	1.000	0	5.27	1.000
4	530.2	6.49	15.20	4.220	3037	4.490	0	13.36	1.000	0	4.29	1.000
						$C_q = 9.09 \times 10^{-4}$		$T_w/T_\delta = 4.17$				
5	377.8	6.38	15.15	2.925	3206	4.102	9.23	12.53	.859	1.266	4.23	.537
6	428.6	6.49	15.22	3.446	4028	4.132	9.07	11.45	.827	1.310	4.09	.551
7	479.4	6.60	15.15	4.160	4698	4.263	8.85	9.60	.664	1.223	3.60	.482
8	530.2	6.48	15.22	4.261	5288	4.167	9.21	8.39	.628	1.379	3.17	.501
						$C_q = 17.0 \times 10^{-4}$		$T_w/T_\delta = 3.94$				
9	377.8	6.39	15.17	3.249	4919	4.102	16.86	5.36	.368	2.312	2.65	.337
10	479.4	6.42	15.12	3.950	6081	3.991	16.24	5.37	.371	2.246	2.57	.344
11	530.2	6.37	15.18	4.264	7511	3.808	17.81	5.17	.387	2.670	1.90	.300
						$C_q = 25.0 \times 10^{-4}$		$T_w/T_\delta = 3.73$				
12	377.8	6.28	15.15	3.185	6517	3.864	24.91	3.50	.240	3.416	1.96	.249
13	428.6	6.20	15.15	3.619	8156	3.640	24.52	3.07	.222	3.540	1.32	.178
14	479.4	6.22	15.15	3.945	8450	3.759	24.90	3.36	.232	3.440	1.68	.225
15	530.2	6.22	15.22	4.298	10166	3.662	25.80	3.40	.254	3.860	1.29	.204
						$C_q = 0$		$T_w/T_\delta = 4.31$ (Repeat Run)				
16	377.8	6.52	15.15	3.057	1716	4.418	0	14.29	1.000	0	7.87	1.000
17	428.6	6.32	15.15	3.163	1993	4.171	0	15.30	1.000	0	7.42	1.000
18	479.4	6.44	15.18	3.679	2347	4.346	0	15.47	1.000	0	7.46	1.000
19	530.2	6.45	15.15	4.260	3023	4.297	0	12.56	1.000	0	6.33	1.000
						$C_q = 0$		$T_w/T_\delta = 4.12$				
20	479.2	6.68	20.05	5.356	3296	4.381	0	11.86	1.000	0	6.16	1.000
21	479.4	6.41	24.95	5.997	3891	4.116	0	9.46	1.000	0	5.30	1.000

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TABLE 2 SUMMARY OF BOUNDARY LAYER PARAMETERS, $T_w/T_A = 4.1$

$T_w/T_\delta = 4.1$

RUN	x	$Re_x \times 10^{-6}$	T_w/T_δ	$C_q \times 10^4$	θ	δ^*	δ	Θ	Re_θ	$\frac{\delta^*}{\theta}$
	mm				mm	mm	mm	mm		
				$C_q = 0$		$T_w/T_\delta = 4.48$				
1	377.8	3.255	4.475	0	.226	3.18	5.4	.238	1947	14.07
2	428.6	3.533	4.480	0	.288	3.66	7.45	.460	2374	12.71
3	479.4	3.880	4.479	0	.312	4.10	8.0	.464	2527	13.12
4	530.2	4.220	4.490	0	.382	4.84	9.2	.644	3037	12.67
				$C_q = 9.09\times10^{-4}$		$T_w/T_\delta = 4.17$				
5	377.8	2.925	4.102	9.23	.414	4.82	8.8	.686	3206	11.64
6	428.6	3.446	4.132	9.07	.501	5.72	10.8	.848	4028	11.42
7	479.4	4.160	4.263	8.85	.541	6.81	12.0	.753	4698	12.59
8	530.2	4.261	4.167	9.21	.658	7.86	14.1	1.070	5288	11.94
				$C_q = 17.9\times10^{-4}$		$T_w/T_\delta = 3.94$				
9	377.8	3.249	4.102	16.86	.572	7.68	12.1	.792	4919	13.43
10	479.4	3.950	3.991	16.24	.738	9.62	15.5	1.070	6081	13.04
11	530.2	4.264	3.808	17.81	.934	10.70	18.0	1.580	7511	11.46
				$C_q = 25.0\times10^{-4}$		$T_w/T_\delta = 3.73$				
12	377.8	3.185	3.864	24.91	.773	9.96	14.8	1.216	6517	12.88
13	428.6	3.619	3.640	24.52	.966	11.20	17.3	1.640	8156	11.59
14	479.4	3.945	3.759	24.90	1.027	12.90	19.7	1.650	8450	12.56
15	530.2	4.298	3.662	25.80	1.250	14.20	22.7	2.250	10166	11.36
				$C_q = 0$		$T_w/T_\delta = 4.31$				
16	377.8	3.057	4.418	0	.212	3.14	5.3	.256	1716	14.81
17	428.6	3.163	4.171	0	.270	3.64	6.7	.272	1993	13.48
18	479.4	3.679	4.346	0	.306	4.42	8.1	.316	2349	14.44
19	530.2	4.260	4.297	0	.376	5.68	10.0	.384	3023	15.11
				$C_q = 0$		$T_w/T_\delta = 4.12$				
20	479.4		4.381	0	.295	4.34	7.9	.352	3296	14.71
21	479.4		4.116	0	.311	4.30	7.9	NC	3891	13.83

TABLE 3 - Run 1

M_δ = 6.60

Re_θ = 1,947

$\frac{T_v}{T_\delta}$ = 4.475

Cq = 0

P_o = 15.18 atm

T_o = 548 °K

T_δ = 56.4 °K

U_δ = 994.31 m/sec

Y (mm)	M	T/T_δ	U/U_δ
14.60	6.60	1.000	1 000
13.33	6.60	1.000	1 000
12.06	6.60	1.000	.999
10.79	6.57	1.007	999
9.52	6.55	1 015	999
8.25	6.47	1 039	.999
7 06	6.40	1 063	999
6.42	6.28	1.097	997
5.79	6.11	1.151	993
5 15	5 88	1 228	.986
4.52	5.55	1.346	975
3.88	5.15	1.515	.960
3.25	4 73	1 727	.940
2 61	4.29	1 990	917
2.36	4.14	2.091	.907
2 11	3.98	2.117	.876
1.85	3 83	2.316	882
1 60	3 67	2.407	.863
1.34	3.53	2.438	.834
1 09	3.30	2 487	787
.838	2.99	2.541	721
.582	2 35	2.972	.614
328	1 46	3.813	433
.270	1.395	3 830	.414

TABLE 4 - Run 2

M_δ = 6.55

Re_θ = 2,374

$\frac{T_v}{T_\delta}$ = 4.480

Cq = 0

P_o = 15.150 atm

T_t = 546 °K

T_δ = 57.2 °K

U_δ = 992 m/sec

Y (mm)	M	T/T_δ	U/U_δ
14.94	6.55	1 000	1.000
12.40	6.55	1 000	1 000
9.86	6.49	1 017	1 000
9.23	6.45	1.031	1 000
8 59	6.37	1.052	998
7.96	6.25	1 086	.995
7.32	6.11	1 130	991
6.69	5 91	1 188	985
6.05	5.70	1 263	977
5.42	5.44	1.355	967
4.78	5 15	1 472	.955
4.15	4.85	1.608	940
3.51	4.55	1 766	.923
2.88	4 25	1.942	.905
2.24	3.96	2.140	884
1.61	3.62	2.382	854
.927	3 12	2.430	744
.787	2.90	2 526	704
.660	2.59	2.733	.655
.533	2.12	3.178	.577
.406	1.63	3.664	.477
337	1 44	3 854	430
.279	1.37	3 829	409

TABLE 5 - Run 3

M_δ = 6.54

Re_θ = 2527

$\frac{T_w}{T_\delta}$ = 4.579

C_1 = 0

P_o = 15.15 atm

T_t = 546 °K

T_δ = 57.3 °K

U_δ = 992 m/sec

Y (cm)	M	T/T_δ	U/U_δ
16.13	6.54	1.000	1.000
13.59	6.52	1.004	1.000
12.32	6.50	1.012	1.000
11.05	6.46	1.025	1.000
9.78	6.38	1.047	.999
9.14	6.31	1.069	.998
8.00	6.11	1.128	.992
6.98	5.81	1.224	.983
6.48	5.63	1.286	.977
5.97	5.43	1.360	.968
5.46	5.22	1.440	.959
4.95	5.01	1.534	.949
4.44	4.77	1.645	.937
3.94	4.54	1.765	.923
3.68	4.44	1.823	.917
2.92	4.09	2.049	.895
2.61	3.87	2.201	.879
1.90	3.61	2.389	.858
1.65	3.48	2.498	.842
1.14	3.18	2.546	.777
1.02	3.01	2.621	.747
.889	2.91	2.630	.721
.762	2.64	2.791	.674
.635	2.36	2.981	.622
.508	1.98	3.323	.553
.381	1.38	4.034	.426
.279	1.12	4.210	.353

TABLE 6 - Run 4

M_δ = 6.49

Re_θ = 3937

$\frac{T_w}{T_\delta}$ = 4.490

P_o = 15.20 atm

T_t = 546 K

T_δ = 57.9 K

U_δ = 990 m/sec

Y (cm)	M	T/T_δ	U/U_δ
16.26	6.49	1.000	1.000
14.99	6.47	1.005	1.000
13.72	6.42	1.021	1.000
12.45	6.36	1.040	.999
11.18	6.25	1.074	.998
9.91	6.07	1.130	.994
8.64	5.81	1.211	.986
7.37	5.46	1.333	.972
6.10	5.03	1.506	.950
4.83	4.56	1.727	.923
3.56	4.07	2.012	.890
2.29	3.57	2.377	.848
2.03	3.47	2.458	.838
1.78	3.34	2.553	.822
1.27	3.16	2.560	.778
1.02	2.92	2.594	.724
.762	2.61	2.712	.661
.508	1.97	3.242	.546
.279	1.17	4.074	.363

TABLE 7 - Run 5

M_δ = 6.38 P_o = 15.15 atm

Re_θ = 3206 T_t = 548 °K

$\frac{T_w}{T_\delta}$ = 4.102 T_δ = 60.4 °K

U_δ = 994 m/sec

Y (mm)	M	T/T_δ	U/U_δ
10.83	6.38	1.000	1.000
10.19	6.31	1.020	.999
9.56	6.18	1.059	997
8.92	6.01	1.109	992
8.29	5.80	1.175	.986
7.65	5.54	1.262	.976
7.02	5.23	1.378	963
6.38	4.93	1.495	.947
5.75	4.63	1.639	.930
5.11	4.33	1.800	.910
4.48	4.01	1.984	.886
3.84	3.76	2.156	.865
3.21	3.50	2.351	.841
2.57	3.27	2.536	.816
1.94	3.02	2.754	.786
1.30	2.71	2.879	.722
.668	2.14	2.994	.581
.414	1.58	3.427	.459
.279	1.15	3.574	.334

TABLE 8 - Run 6

M_δ = 6.49 P_o = 15.22 atm

Re_θ = 4,028 T_t = 548 °K

$\frac{T_w}{T_\delta}$ = 4.132 T_δ = 58.1 °K

U_δ = 992. m/sec

Y (mm)	M	T/T_δ	U/U_δ
19.94	6.49	1.000	1.000
13.59	6.45	1.011	.999
12.95	6.42	1.022	.999
12.32	6.36	1.038	.998
11.68	6.27	1.064	.996
11.05	6.15	1.099	.993
10.41	6.02	1.138	.988
9.78	5.83	1.197	.982
9.14	5.63	1.261	974
8.51	5.41	1.342	.965
7.87	5.18	1.430	.953
7.24	4.93	1.537	.941
6.60	4.68	1.652	.926
5.97	4.42	1.781	.909
5.33	4.20	1.907	.892
4.70	3.96	2.051	.873
4.06	3.74	2.196	.853
3.43	3.49	2.381	.829
2.79	3.27	2.551	804
2.16	3.08	2.698	778
1.52	2.76	2.935	.727
1.27	2.63	2.976	.699
1.02	2.42	3.039	.649
.762	2.15	3.055	579
.508	1.71	3.286	.476
.381	1.41	3.538	408
.279	1.15	3.737	.341

TABLE 9 - Run 7

M_δ = 6.60

Re_n = 4698

$\frac{T_w}{T_\delta}$ = 4.26

C_f = 9.85x10^{-4}

P_o = 15.15 atm

T_t = 547 K

T_δ = 56.1 K

U_δ = 99. m/sec

Y (mm)	M	T/T_δ	U/U_δ
18 69	6.60	1.000	1 000
16 15	6.55	1.013	1.000
14 88	6.48	1 035	1.000
13 61	6 36	1 070	997
12.34	6 15	1 135	.993
11 71	6.01	1.179	989
11.07	5 84	1.238	984
10 44	5 64	1.306	978
9 804	5 47	1.368	969
9.169	5.25	1.459	.961
8.534	5.03	1.553	.949
7.899	4.81	1.653	.937
7.264	4.59	1.768	.925
6.629	4.38	1.881	.911
5.994	4.15	2.017	.894
5.359	3.94	2.157	.876
4.724	3.72	2.314	.857
4.089	3.51	2.472	836
3 454	3.28	2.663	.812
2.819	3.07	2.861	.786
2.184	2.82	3 120	.755
1 549	2.58	3.289	.710
914	2.13	3.381	.593
.660	1 77	3.586	.508
.406	1.29	3.935	.387
279	1.10	3.967	.333

TABLE 10 - Run 8

M = 6.48

Re = 5,288

$\frac{T_w}{T}$ = 4.167

C_f = 9.21-10^{-4}

P = 15.22 atm

T = 548 K

T = 58.3 K

U = 992 m/sec

Y (cm)	M	T/T_δ	U/U_δ
20.09	6.48	1.000	1 000
18 62	6.47	1.003	1 000
17.55	6 40	1.022	999
16.28	6.29	1.055	997
15.01	6.14	1.100	994
13.74	5.93	1.167	.988
12 47	5.63	1.267	978
11.20	5.21	1 380	963
9.951	4.95	1.529	.945
8.661	4.58	1 703	.922
7 391	4 25	1 873	897
6.121	3.84	2 120	864
4 851	3.46	2.394	.826
3.581	3 07	2.708	780
2 311	2 6r	3 059	723
1 676	2.49	3.165	.684
1 295	2.29	3 212	634
1 041	2 14	3.185	.591
787	1.88	3 289	.527
533	1 40	3 703	417
406	1 093	3 966	337
.279	.916	4.012	.283

TABLE 11 - Run 9

M_δ = 6.39 P_o = 15.17 atm

Re_θ = 4,919 T_t = 546 °K

$\frac{T_w}{T_\delta}$ = 4.102 T_δ = 59.5 °K

C_q = 16.86x10^{-4} U_δ = 989 m/sec

Y (mm)	M	T/T_δ	U/U_δ
20.55	6.39	1.000	1.000
14.20	6.29	1.030	.998
12.93	6.06	1.099	.994
11.66	5.72	1.216	.987
10.39	5.26	1.397	.973
9.75	5.01	1.505	.962
9.12	4.93	1.526	.952
8.48	4.68	1.749	.928
7.85	4.22	1.898	.909
7.21	3.95	2.067	.887
6.58	3.71	2.228	.865
5.94	3.46	2.412	.839
5.31	3.22	2.599	.813
4.67	2.99	2.814	.783
4.037	2.76	3.027	.751
3.402	2.57	3.216	.721
2.767	2.36	3.436	.685
2.132	2.15	3.650	.644
1.497	1.86	3.847	572
.862	1.43	3.882	.440
.227	.723	4.033	.227

TABLE 12 - Run 10

M = 6.422 P_o = 15.12 atm

Re_θ = 6,081 T_t = 547 °K

$\frac{T_w}{T}$ = 3.991 T_δ = 59.1 °K

Cq = 16.24x10^{-4} U_δ = 990 m/sec

Y (mm)	M	T/T_δ	U/U_δ
21.23	6.42	1.000	1.000
19.96	6.38	1.010	.999
18.69	6.32	1.032	.999
17.42	6.20	1.070	.998
16.79	6.12	1.095	.997
16.15	6.02	1.124	993
15.52	5.89	1 166	.990
14.88	5.75	1.212	.986
14.25	5.50	1.264	.979
13.61	5.41	1.331	.972
12.98	5.22	1.404	.964
12.34	5.04	1.482	.955
11.71	4.84	1.570	944
11.07	4.63	1.666	.930
10.44	4.43	1.765	.916
9.804	4.23	1.873	.901
9.169	4.03	1.996	.886
8.534	3.82	2.122	.867
7.899	3.64	2.251	.849
7.264	3.44	2.395	.829
6.629	3.27	2.522	.808
5.994	3.05	2.714	.782
5.359	2.87	2.880	.757
4.724	2.71	3.025	.734
4.089	2.49	3.255	.699
3.454	2.37	3.333	.673
2.819	2.15	3.587	.634
2.184	1.92	3.848	.588
1.930	1.86	3.897	.570
1.676	1.77	3.934	.546
1.422	1.65	3.954	.513
1.168	1.50	4.004	.468
.914	1.36	3.980	.424
.660	1.10	4.091	.348
.406	.714	4.244	.229
.279	.534	4.216	.171

TABLE 13 - Run 11

M_δ = 6.37

Re_θ = 7,511

$\frac{T_w}{T_\delta}$ = 3.808

C_q = 17.81x10^{-4}

P_o = 15 18 atm

T_t = 547 K

T_δ = 60.0 K

U_δ = 989 m/sec

Y (mm)	M	T/T_δ	U/U_δ
22.581	6.37	1.000	1.000
21.311	6.31	1.017	.999
20.041	6.21	1.046	997
18.771	6.055	1 093	994
17.501	5.842	1.158	.987
16.231	5.57	1 248	977
14.961	5.229	1.372	.962
13.691	4.932	1.491	.945
12.421	4.562	1.660	.923
11.151	4.195	1.851	.896
9.881	3.872	2.034	.867
8.611	3.551	2.243	.835
7.341	3.228	2.473	.797
6.071	2.903	2.724	752
4.801	2.581	2.982	.700
3.531	2.26	3 256	640
2.261	1.965	3.484	576
.991	1 493	3.458	.436
.483	1.037	3.593	.309
.279	.571	3.848	.176

TABLE 14 - Run 12

M_δ = 6.287

Re_θ = 6,517

$\frac{T_w}{T_\delta}$ = 3.864

C_q = 24 91x10^{-4}

P_o = 15.15 atm

T_t = 547 K

T_δ 61 9 K

U_δ = 990 m/sec

Y (mm)	M	T/T_δ	U/U_δ
18.74	6.28	1.000	1 000
18.11	6.24	1.011	1.000
16.84	6.14	1.044	.999
15.57	5.92	1 110	.994
14.30	5 58	1.222	.984
13.03	5 13	1.390	964
11.76	4 67	1.589	.937
10.49	4 17	1 839	.901
9.218	3.69	2.139	.860
7.948	3.24	2.455	.809
6.678	2.82	2 801	753
5.408	2.43	3 169	689
4.138	2.08	3.528	623
2.868	1.74	3.872	.547
2.233	1.57	4.010	499
1 598	1.38	4.074	443
.963	.971	4.212	.317
.328	.685	3.897	215
.279	.491	4.010	156

TABLE 15 - Run 13

M_s = 6.204 P_o = 15.15 atm

Re_θ = 8,156 T_t = 547 °K

$\frac{T_w}{T_\delta}$ = 3.640 T_δ = 62.9 °K

Cq = 24.52x10^{-4} U_δ = 987 m/sec

Y (mm)	M	T/T_δ	u/U_δ
26.24	6.20	1.000	1.000
19.89	6.11	1.029	.999
18.62	5.98	1.069	.997
17.35	5.77	1.130	.988
16.08	5.49	1.220	.977
14.81	5.06	1.376	.957
13.54	4.66	1.542	.932
12.27	4.15	1.797	.897
11.63	4.02	1.862	.883
11.00	3.75	2.026	.861
10.36	3.54	2.162	.839
9.728	3.35	2.293	.818
9.093	3.16	2.430	.794
8.458	2.98	2.577	.770
7.823	2.79	2.734	.743
7.188	2.60	2.893	.713
6.553	2.44	3.032	.685
5.918	2.30	3.142	.657
5.283	2.14	3.292	.625
4.648	2.03	3.355	.599
4.013	1.82	3.562	.555
3.378	1.68	3.682	.520
2.743	1.56	3.709	.486
2.108	1.39	3.772	.436
1.473	1.25	3.760	.388
.838	.980	3.734	.305
.279	.516	3.734	.161

TABLE 16 - Run 14

M_δ = 6.22 P_o = 15.15 atm

Re_θ = 8450 T_t = 547 K

$\frac{T_w}{T_\delta}$ = 3.759 T_δ = 62.5 K

Cq = 24.90x10^{-4} U_δ = 987 m/sec

Y (mm)	M	T/T_δ	U/U_δ
27.61	6.22	1.000	1.000
26.34	6.21	1.005	1.000
25.07	6.19	1.011	1.000
21.89	6.15	1.064	.998
20.62	5.89	1.105	.995
18.72	5.52	1.225	.982
18.08	5.37	1.279	.975
16.82	5.05	1.398	.956
15.54	4.68	1.555	.938
14.91	4.49	1.642	.926
13.64	4.12	1.836	.898
13.01	3.94	1.944	.883
12.37	3.76	2.060	.867
11.74	3.58	2.177	.849
11.10	3.40	2.310	.831
10.46	3.24	2.426	.812
9.830	3.10	2.538	.793
9.195	2.93	2.674	.770
8.560	2.74	2.845	.744
7.925	2.59	2.990	.719
7.290	2.44	3.112	.693
6.655	2.31	3.226	.668
6.020	2.15	3.387	.637
5.395	2.03	3.501	.610
4.750	1.89	3.637	.579
4.115	1.77	3.741	.550
3.480	1.64	3.853	.518
2.845	1.52	3.945	.486
2.210	1.38	4.041	.440
1.575	1.19	4.132	.388
.940	.977	3.975	.313
.686	.815	3.946	.260
.432	.551	3.965	.176
.279	.443	3.893	.140

TABLE 17 - Run 15

M_δ = 6.22 P_o = 15.22 atm

Re_θ = 10,166 T_t = 547 K

$\frac{T_w}{T_\delta}$ = 3.663 T_δ = 62.5 K

C_q = 25.80x10^{-4} U_δ = 987 m/sec

Y (mm)	M	T/T_δ	U/U_δ
30.23	6.22	1.000	1.000
27.69	6.22	1.002	1.000
25.15	6.11	1.033	.998
22.61	5.84	1.116	.992
20.07	5.35	1.278	.971
17.53	4.69	1.540	.936
14.99	4.06	1.851	.888
12.45	3.40	2.262	.821
9.906	2.85	2.664	.747
7.366	2.32	3.097	.656
4.826	1.86	3.423	.553
2.286	1.40	3.708	.432
1.016	1.04	3.529	.313
.279	.593	3.512	.179

TABLE 18 - Run 16

M_δ = 6.52 P_o = 15.2 atm

Re_θ = 1716 T_t = 548 K

$\frac{T_w}{T_\delta}$ = 4.418 T_δ = 57.6 K

C_q = 0 U_δ = 992 m/sec

Y (mm)	M	T/T_δ	U/U_δ
16.28	6.52	1.000	1.000
13.74	6.52	1.000	1.000
11.20	6.49	1.000	1.000
9.931	6.48	1.012	1.000
8.661	6.47	1 015	1.000
7.391	6.39	1.040	.999
6.121	6.19	1 097	.994
4.851	5.74	1.250	.984
4.216	5.38	1.386	.971
3.835	5.17	1.470	.962
3.581	4.92	1.593	.952
3.327	4.73	1.687	.942
3.073	4.53	1.792	.931
2.819	4.34	1.913	.920
2.565	4.17	2.023	.909
2.311	4.00	2.141	.898
2.057	3.80	2.298	.883
1.930	3.75	2.326	.877
1.803	3.66	2.397	869
1.549	3.49	2.535	.853
1.295	3.32	2.667	.833
1.041	3.10	2.830	.800
.787	2.69	3.155	.733
.533	2.05	3.714	606
.279	1.75	3.576	.507

TABLE 19 - Run 17

M_δ = 6.32

Re_θ = 1993

$\frac{Tw}{T_\delta}$ = 4.171

Cq = 0

P_o = 15.2 atm

T_t = 548 K

T_δ = 61.0 K

U_δ = 990 m/sec

Y (mm)	M	T/T_δ	U/U_δ
12.47	6.32	1.000	1.000
9.931	6.29	1.011	1.000
8.661	6.20	1.039	.999
7.391	5.97	1.108	.995
6.121	5.60	1.234	.984
4.851	5.03	1.429	.950
3.581	4.39	1.779	.927
2.946	4.02	2.015	.903
2.565	3.87	2.111	.889
2.311	3.72	2.234	.879
2.057	3.61	2.317	.869
1.803	3.49	2.410	.858
1.549	3.36	2.516	.843
1.295	3.23	2.613	.826
1.041	3.04	2.713	.792
.787	2.76	2.832	.734
.533	2.17	3.221	.616
.279	1.24	4.010	.392

TABLE 20 - Run 18

M_δ = 6.44

Re_θ = 2349

$\frac{Tw}{T_\delta}$ = 4.346

Cq = 0

P_o = 15.2 atm

T_t = 547 K

T_δ = 59.0 K

U_δ = 991 m/sec

Y (mm)	M	T/T_δ	U/U_δ
15.29	6.44	1.000	1.000
12.75	6.43	1.002	1.000
10.21	6.30	1.042	.999
7.671	5.79	1.206	.989
6.401	5.36	1.366	.974
5.131	4.86	1.583	.950
3.861	4.30	1.889	.918
2.591	3.76	2.261	.878
1.956	3.48	2.490	.854
1.321	3.16	2.763	.815
.686	2.48	3.172	.685
.432	1.78	3.778	.538
.279	1.40	3.988	.435

TABLE 21 - Run 19

M_δ = 6.45
Re_θ = 3023
$\frac{Tw}{T_\delta}$ = 4.297
C_q = 0
P_o = 15.2 atm
T_t = 547 K
T_δ = 58.6 K
U_δ = 991 m/sec

Y (mm)	M	T/T_δ	U/U_δ
27.20	6.45	1.000	1.000
24.66	6.45	1.002	1.000
22.12	6.44	1.004	1.000
19.58	6.41	1.012	.999
17.04	6.38	1.020	.999
14.50	6.34	1.034	.998
13.23	6.28	1.051	.998
11.96	6.18	1.081	.996
10.69	6.03	1.132	.994
9.423	5.81	1.208	.989
8.153	5.47	1.333	.979
6.883	5.04	1.514	.962
5.613	4.58	1.742	.938
4.343	4.13	2.004	.907
3.708	3.91	2.150	.889
3.073	3.65	2.350	.867
2.819	3.56	2.422	.859
2.565	3.54	2.436	.855
2.311	3.37	2.594	.840
2.057	3.26	2.693	.829
1.803	3.14	2.806	.816
1.549	3.04	2.901	.803
1.295	2.91	3.017	.783
1.041	2.71	3.145	.746
.787	2.42	3.313	.681
.533	1.88	3.750	.565
.406	1.54	4.042	.479
.279	1.07	4.459	.349

TABLE 22 - Run 20

M_δ = 6.68
Re_θ = 3296
$\frac{Tw}{T_\delta}$ = 4.381
C_q = 0
P_o = 20.05 atm
T_t = 550 K
T_δ = 55.5 K
U_δ = 998 m/sec

Y (mm)	M	T/T_δ	U/U_δ
19.20	6.68	1.000	1.000
12.85	6.65	1.009	1.000
11.58	6.63	1.016	1.000
10.31	6.55	1.039	1.000
9.677	6.48	1.060	.999
9.042	6.37	1.093	.997
8.407	6.24	1.135	.995
7.772	6.06	1.193	.990
7.137	5.84	1.266	.984
6.502	5.60	1.356	.976
5.867	5.32	1.468	.965
5.232	5.05	1.586	.952
4.597	4.77	1.719	.937
3.962	4.46	1.883	.920
3.327	4.19	2.058	.901
2.692	3.90	2.266	.878
2.438	3.77	2.365	.867
2.184	3.64	2.464	.857
1.930	3.50	2.591	.843
1.676	3.39	2.683	.831
1.422	3.25	2.829	818
1.168	3.09	2.970	.798
.914	2.93	3.063	.767
.787	2.80	3.120	.741
.660	2.58	3.287	.701
.533	2.33	3.439	646
.406	1.93	3.703	.557
.279	1.45	4.085	.439

TABLE 23 - Run 21

M_δ = 6.41

Re_θ = 3891

$\frac{Tv}{T_\delta}$ = 4.116

Cq = 0

P_o = 24.95 atm

T_t = 550 K

T_δ = 60.0 K

U_δ = 994 m/sec

Y (mm)	M	T/T_δ	U/U_δ
21.82	6.41	1.000	1.000
15.47	6.41	1.000	1.000
11.66	6.34	1.019	.999
10.39	6.30	1.032	.998
9.119	6.16	1.076	.998
7.849	5.87	1.171	.991
6.579	5.46	1.317	.977
5.309	4.94	1.530	.954
4.039	4.38	1.812	.920
2.769	3.75	2.223	.873
1.499	3.12	2.749	.808
.864	2.73	3.059	.746
.737	2.60	3.053	.709
.610	2.40	3.259	.675
.483	2.09	3.472	.607
.356	1.65	3.837	.505
.279	1.36	4.032	.427

TABLE 24 SUMMARY OF SKIN FRICTION AND HEAT TRANSFER DATA, T_w/T_δ = 5.2

T_w/T_δ = 5.2

RUN	X	M_δ	P_o	$Re_x \times 10^{-6}$	Re_θ	T_w/T_δ	$C_q \times 10^4$	$C_f \times 10^4$	C_f/C_{fo}	$2C_q/C_{fo}$	$St \times 10^4$	$\frac{St}{St_o}$
						C_q = 0		T_w/T_δ = 5.44				
22	377.8	6.46	15.22	3.028	1619	5.45	0	15.6			6.77	
23	428.6	6.46	15.25	3.323	1853	5.116	0	11.85	1.000	0	6.42	1.000
24	479.4	6.62	15.08	4.210	2520	5.722	0	14.74	1.000	0	6.69	1.000
25	530.2	6.45	15.12	4.285	2667	5.427	0	12.10	1.000	0	5.18	1.000
						$C_q = 8.77 \times 10^{-4}$		T_w/T_δ = 5.45				
26	377.8	6.45	15.01	3.468	2994	5.210	8.944	10.91	.656	1.076	5.45	.754
27	428.6	6.50	15.15	3.552	3448	5.502	8.932	9.11	.738	1.508	4.66	.726
28	479.4	6.64	15.08	4.438	4554	5.741	8.432	10.83	.735	1.144	4.26	.637
29	530.2	6.55	15.05	4.701	5281	5.348	8.756	7.82	.646	1.439	3.97	.765
						$C_q = 17.2 \times 10^{-4}$		T_w/T_δ = 5.07				
30	377.8	6.21	15.22	2.894	4519	4.752	17.57	6.22	.374	2.114	3.19	.441
31	428.6	6.30	15.15	3.495	5365	4.954	17.14	5.76	.486	2.892	3.28	.511
32	479.4	6.39	15.20	3.885	6223	5.119	17.45	6.75	.458	2.368	2.68	.401
33	530.2	6.62	15.05	5.050	8048	5.468	16.46	8.14	.673	2.721	2.58	.498
						$C_q = 24.6 \times 10^{-4}$		T_w/T_δ = 4.85				
34	377.8	6.27	15.08	3.264	6826	4.800	24.42	6.26	.377	2.938	2.26	.312
35	428.6	6.33	15.12	4.045	8651	4.872	22.96	3.98	.336	3.875	1.85	.288
36	479.4	6.27	15.15	3.940	8969	4.838	26.47	2.58	.184	3.592	1.98	.276
37	530.2	6.37	15.12	4.773	10640	4.887	24.44	5.34	.441	4.040	1.88	--
						C_q = 0		T_w/T_δ = 5.58				
38	377.8	6.53	15.05	3.141	1713	5.582	0	16.62	1.000	0	7.23	1.000

TABLE 25 SUMMARY OF BOUNDARY LAYER PARAMETERS, T_w/T_δ = 5.2

T_w/T_δ=5.2

RUN	x	$Re_x \times 10^{-6}$	T_w/T_δ	$C_q \times 10^{-4}$	θ	δ^*	δ	Θ	Re_θ	$\frac{\delta^*}{\theta}$
				C_q = 0		T_w/T_δ = 5.44				
22	377.8	3.028	5.45	0	.202	3.22	5.65	NC	1619	
23	428.6	3.323	5.116	0	.239	3.54	6.70	NC	1853	14.81
24	479.4	4.210	5.722	0	.287	4.77	8.30	.300	2520	16.62
25	530.2	4.285	5.427	0	.330	5.02	9.15	NC	2667	15.21
				C_q = 8.77x10^{-4}		T_w/T_δ = 5.45				
26	377.8	3.468	5.210	8.944	.370	5.25	9.00	.328	2994	14.19
27	428.6	3.552	5.502	8.932	.416	5.94	10.70	NC	3448	14.29
28	479.4	4.438	5.741	8.482	.492	8.04	12.70	.604	4554	16.34
29	530.2	4.701	5.348	8.756	.596	8.58	14.20	1.016	5281	14.33
				C_q = 17.2x10^{-4}		T_w/T_δ = 5.07				
30	377.8	2.894	4.752	17.570	.590	7.42	12.00	.880	4519	12.58
31	428.6	3.495	4.954	17.140	.658	8.65	14.20	NC	5365	13.14
32	479.4	3.885	5.119	17.450	.964	11.06	16.50	1.285	6223	11.47
33	530.2	5.050	5.468	16.460	.845	12.74	19.4	1.620	8048	15.08
				C_q = 24.6x10^{-4}		T_w/T_δ = 4.85				
34	377.8	3.264	4.800	24.420	.790	11.24	16.50	1.28	6826	14.23
35	428.6	4.045	4.872	22.960	.917	14.00	21.00	1.39	8651	15.28
36	479.4	3.940	4.838	26.470	1.090	14.26	19.70	1.86	8969	13.07
37	530.2	4.773	4.887	24.440	1.182	16.56	24.00	2.14	10640	14.01
				C_q = 0		T_w/T_δ = 5.58				
38	377.8	3.141	5.582	0	.206	3.47	5.90	.214	1713	16.85

TABLE 26 - Run 22

M_δ = 6.46 P_o = 15.22 atm

Re_θ = 1619 T_t = 546°K

T_w/T_δ = 5.45 T_δ = 58.7°K

C_q = 0 U_δ = 992 m/sec

Y mm	M	T/T_δ	U/U_δ
12.66	6.45	1.000	1.000
11.39	6.46	1.000	1.000
10.12	6.44	1.008	1.000
8.217	6.41	1.015	1.000
7.582	6.37	1.027	.999
6.947	6.30	1.051	.999
6.312	6.17	1.087	.996
5.677	5.98	1.147	.991
5.042	5.68	1.249	.983
4.407	5.30	1.399	.971
3.772	4.85	1.610	.953
3.137	4.41	1.869	.933
2.502	4.03	2.131	.910
1.867	3.68	2.420	.885
1.613	3.51	2.552	.869
1.359	3.27	2.722	.834
1.105	2.93	2.940	.778
.851	2.46	3.331	.695
.597	1.84	4.029	.573
.343	1.18	4.843	.403
.165	1.01	4.828	.343

TABLE 27 - Run 23

M_δ = 6.46 P_o = 15.25 atm

Re_θ = 1853 T_t = 550°K

T_w/T_δ = 5.116 T_δ = 58.8°K

C_q = 0 U_δ = 993 m/sec

Y mm	M	T/T_δ	U/U_δ
10.29	6.46	1.000	1.000
7.747	6.24	1.065	.996
6.477	5.90	1.170	.988
5.207	5.39	1.356	.971
3.937	4.78	1.628	.944
2.667	4.18	1.984	.911
1.397	3.37	2.559	.836
1.143	2.93	2.909	.773
.889	2.34	3.515	.679
.635	1.60	4.459	.522
.508	1.22	4.933	.420
.381	.991	5.093	.346
.330	.941	5.069	.328

TABLE 28 Run 24

M_δ = 6.62 | P_t = 15.08 atm

Re_θ = 2520 | T_t = 546°K

$\frac{Tw}{T_\delta}$ = 5.722 | T_δ = 56.0°K

C_q = 0 | U_δ = 993 m/sec

Y mm	M	T/T_δ	U/U_δ
13.27	6.62	1.000	1.000
12.00	6.55	1.021	1.000
10.73	6.43	1.059	1.000
10.10	6.35	1.084	.999
9.462	6.24	1.117	.997
8.827	6.09	1.168	.994
8.192	5.92	1.227	.991
7.557	5.70	1.309	.984
6.922	5.47	1.397	.977
6.287	5.22	1.502	.966
5.652	4.96	1.627	.955
5.017	4.69	1.769	.941
4.382	4.43	1.919	.928
3.747	4.16	2.101	.912
3.112	3.91	2.298	.895
2.858	3.80	2.392	.887
2.604	3.67	2.500	.877
2.350	3.58	2.586	.869
2.096	3.45	2.706	.858
1.842	3.34	2.816	.846
1.588	3.20	2.926	.827
1.334	3.03	3.038	.797
1.080	2.78	3.197	.751
.953	2.63	3.299	.721
.826	2.45	3.441	.686
.699	2.18	3.741	.636
.572	1.79	4.260	.559
.445	1.40	4.829	.466
.318	1.11	5.162	.380
.279	.979	5.311	.341

TABLE 29 - Run 25

M_δ = 6.45 | P_t = 15.12 atm

Re_θ = 2667 | T_t = 546°K

$\frac{Tw}{T_\delta}$ = 5.427 | T_δ = 58.6°K

C_q = 0 | U_δ = 990 m/sec

Y mm	M	T/T_δ	U/U_δ
15.29	6.45	1.000	1.000
14.02	6.43	1.006	1.000
13.39	6.41	1.010	.998
12.75	6.38	1.020	.999
12.12	6.33	1.036	1.000
11.48	6.28	1.051	.999
10.85	6.20	1.076	.998
10.21	6.10	1.109	.996
9.576	5.98	1.150	.995
8.941	5.84	1.199	.991
8.306	5.66	1.259	.985
7.671	5.46	1.334	.978
7.036	5.25	1.414	.969
6.401	5.21	1.423	.965
5.766	4.79	1.620	.946
5.131	4.55	1.747	.933
4.496	4.31	1.888	.918
3.861	4.06	2.057	.903
3.226	3.80	2.247	.883
2.591	3.54	2.467	.862
1.956	3.29	2.699	.838
1.829	3.19	2.806	.829
1.575	3.06	2.900	.808
1.321	2.96	2.861	.778
1.067	2.59	3.146	.712
.813	2.20	3.496	.638
.686	1.89	3.861	.577
.559	1.56	4.306	.502
.432	1.38	4.488	.452

TABLE 30 - Run 26

M_δ = 6.45 P_t = 15.01 atm

Re_θ = 2994 T_t = 546°K

T_w/T_δ = 5.210 T_δ = 59.2°K

C_q = 8.94 x 10^{-4} U_δ 995 m/sec

Y mm	M	T/T_δ	U/U_δ
13.75	6.45	1.000	1.000
12.48	6.44	1.003	1.000
11.21	6.39	1.000	1.000
9.944	6.23	1.047	.999
8.674	5.88	1.152	.988
7.404	5.32	1.353	.970
6.134	4.67	1.644	.937
4.864	4.03	2.010	.895
3.594	3.47	2.449	.851
2.324	3.00	2.892	.800
1.689	2.74	3.147	.760
1.054	2.25	3.517	.659
.419	1.15	4.720	.392
.165	.795	4.814	.273

TABLE 31 - Run 27

M_δ = 6.50 P_o = 15.15 atm

Re_θ = 3448 T_t = 548°K

$\frac{T_w}{T_\delta}$ = 5.302 T_δ = 58.0°K

C_q = 8.93 x 10^{-4} U_δ = 992 m/sec

Y mm	M	$T T_\delta$	U/U_δ
17.56	6.50	1 000	1.000
15.02	6.50	1.000	1 000
12.48	6.39	1.035	1 000
11.21	6.20	1.091	.996
9.940	5.87	1.196	.987
8.672	5 42	1.356	971
7.402	4.92	1.572	.948
6.132	4.42	1 920	.920
4.862	3.95	2 121	.886
.592	3.50	2.467	846
2.322	3.06	2.899	.800
1.687	2.723	3.237	.754
1.052	1.996	3.984	.613
.417	.851	5.371	.303
.165	.673		

TABLE 32 - Run 28

M_δ = 6.64 P_o = 15.08 atm

Re_θ = 4554 T_t = 546 °K

$\frac{T_w}{T_\delta}$ = 5.74 T_δ = 55.7 °K

C_q = 8.432 x 10^{-4} U_δ = 994 m/sec

Y mm	M	T/T_δ	U/U_δ
19.58	6.64	1.000	1.000
17.04	6.54	1.032	1.000
15.77	6.43	1.068	1.000
14.50	6.24	1.126	.998
13.23	6.01	1.205	.994
11.96	5.70	1.314	.985
10.69	5.30	1.479	.972
9.423	4.89	1.674	.952
8.153	4.46	1.907	.929
6.883	4.05	2.169	.899
6.268	3.81	2.365	.882
5.613	3.62	2.505	.864
4.978	3.42	2.675	.843
4.343	3.24	2.853	.824
4.089	3.14	2.949	.814
3.835	3.08	3.005	.805
3.581	2.99	3.109	.795
3.327	2.91	3.205	.786
3.073	2.84	3.289	.777
2.819	2.78	3.356	.768
2.565	2.70	3.444	.756
2.311	2.59	3.612	.742
2.057	2.50	3.718	.727
1.803	2.43	3.783	.712
1.549	2.30	3.909	.685
1.295	2.13	4.054	.646
1.041	1.92	4.247	.595
.787	1.62	4.573	.522
.533	1.21	5.085	.418
.406	1.02	5.268	.353
.279	.834	5.418	.292

TABLE 33 - Run 29

M_δ = 6.55 P_o = 15.05 atm

Re_θ = 5281 T_t = 548 °K

$\frac{T_w}{T_\delta}$ = 5.348 T_δ = 57.3 °K

C_q = 8.76 x 10^{-4} U_δ = 993 m/sec

Y mm	M	T/T_δ	U/U_δ
18.31	6.55	1.000	1.000
17.04	6.42	1.036	.999
15.77	6.22	1.098	.996
14.50	5.95	1.185	.990
13.23	5.63	1.298	.980
11.96	5.29	1.437	.969
10.69	4.92	1.601	.952
9.423	4.56	1.786	.931
8.153	4.17	2.021	.905
6.883	3.80	2.268	.875
5.613	3.46	2.540	.843
4.978	3.26	2.712	.821
4.343	3.11	2.861	.803
3.708	2.92	3.054	.780
3.073	2.73	3.279	.755
2.438	2.53	3.525	.725
1.803	2.31	3.771	.686
1.549	2.20	3.858	.660
1.295	2.08	3.921	.629
1.041	1.86	4.103	.576
.787	1.52	4.474	.493
.660	1.26	4.832	.421
.533	1.03	5.084	.355
.406	.844	5.224	.295
.279	.614	5.583	.149

TABLE 34 - Run 30

M_δ = 6.21 P_o = 15.22 atm

Re_θ = 4519 T_t = 547 °K

$\frac{Tv}{T_\delta}$ = 4.752 T_δ = 63.6 °K

C_q = 17.6 x 10^{-4} U_δ = 993 m/sec

Y	M	T/T_δ	U/U_δ
14.00	6.21	1.000	1.000
12.72	5.97	1.071	.995
11.46	5.63	1.178	.984
10.18	5.11	1.367	.962
9.550	4.79	1.506	.946
8.915	4.50	1.644	.930
8.280	4.24	1.779	.912
7.645	3.97	1.938	.891
7.010	3.73	2.095	.869
6.375	3.48	2.274	.844
5.740	3.25	2.444	.820
5.105	3.03	2.638	.793
4.470	2.83	2.827	.768
3.835	2.62	3.045	.738
3.200	2.44	3.249	.707
2.565	2.24	3.491	.674
1.930	2.01	3.731	.626
1.295	1.66	4.016	.535
1.041	1.42	4.181	.469
.787	1.14	4.469	.390
.533	.802	4.741	.281
.406	.689	4.750	.242
.330	.631	4.744	.221

TABLE 35 Run 31

M_δ = 6.30 P_t = 15.15 atm

Re_θ = 5365 T_t = 547 °K

$\frac{Tv}{T_\delta}$ = 4.954 T_δ = 61.6 °K

C_q = 17.14 x 10^{-4} U_δ = 991 m/sec

Y	M	T/T_δ	U/U_δ
17.73	6.30	1.000	1.000
14.99	6.03	1.060	.995
13.92	5.76	1.168	.989
12.65	5.40	1.292	.975
11.38	4.96	1.470	.955
10.11	4.49	1.698	.929
8.839	4.11	1.908	.901
7.569	3.68	2.189	.865
6.299	3.28	2.503	.824
5.029	2.89	2.868	.777
3.759	2.54	3.238	.725
3.124	2.35	3.468	.695
2.489	2.18	3.668	.662
1.854	1.94	3.923	.611
1.219	1.60	4.163	.519
.584	.924	4.778	.321
.330	.673	4.851	.237

TABLE 36 - Run 32

M_δ = 6.39 P_o = 15.20 atm

Re_θ = 6223 T_t = 546 °K

$\frac{T_w}{T_\delta}$ = 5.119 T_δ = 59.7 °K

C_q = 17.45 x 10^{-4} U_δ = 989 m/sec

Y mm	M	T/T_δ	U/U_δ
24.97	6.39	1.000	1.000
22.43	6.35	1.011	1.000
19.89	6.23	1.051	1.000
18.62	6.09	1.098	.999
17.98	6.00	1.127	.998
17.35	5.89	1.166	.995
16.71	5.73	1.222	.992
16.08	5.58	1.274	.986
15.44	5.36	1.358	.979
14.81	5.19	1.427	.971
14.17	5.04	1.490	.963
13.54	4.86	1.569	.954
12.90	4.69	1.653	.944
12.27	4.47	1.773	.931
11.63	4.28	1.882	.918
11.00	4.09	1.995	.904
10.36	3.91	2.111	.889
9.728	3.72	2.241	.873
9.093	3.55	2.376	.856
8.458	3.38	2.510	.837
7.823	3.21	2.653	.818
7.188	3.05	2.791	.798
6.553	2.90	2.943	.778
5.918	2.74	3.094	.755
5.283	2.59	3.261	.731
4.648	2.44	3.424	.706
4.013	2.27	3.611	.677
3.378	2.13	3.781	.649
2.743	1.99	3.957	.619
2.108	1.85	4.075	.585
1.473	1.63	4.265	.527
.838	1.23	4.539	.411
.533	1.03	4.645	.348

TABLE 37 - Run 33

M_δ = 6.62 P_o = 15.05 atm

Re_θ = 8048 T_t = 546 °K

$\frac{T_w}{T_\delta}$ = 5.468 T_δ = 56.0 °K

C_q = 16.46 x 10^{-4} U_δ = 993 m/sec

Y mm	M	T/T_δ	U/U_δ
24.66	6.62	1.000	1.000
22.12	6.41	1.063	.998
19.58	6.04	1.180	.992
17.04	5.45	1.396	.973
14.50	4.72	1.737	.939
11.96	4.03	2.148	.892
9.423	3.37	2.662	.831
6.883	2.76	3.272	.754
4.343	2.22	3.908	.664
3.073	1.97	4.229	.612
2.438	1.81	4.457	.578
1.803	1.67	4.558	.560
1.549	1.53	4.727	.502
1.295	1.43	4.761	.473
1.041	1.29	4.871	.431
.787	1.09	5.054	.370
.660	.991	5.123	.339
.533	.922	5.132	.316
.406	.799	5.213	.276
.279	.612	5.353	.214

TABLE 38 - Run 34

M_δ = 6.27 P_o = 15.08 atm

Re_θ = 6826 T_t = 546 °K

$\frac{T_w}{T_\delta}$ = 4.800 T_δ = 61.9 °K

C_q = 24.42 x 10^{-4} U_δ = 988 m/sec

Y	M	T/T_δ	U/U_δ
23.52	6.27	1.000	1.000
20.98	6.27	1.000	1.000
18.44	6.12	1.044	.998
15.90	5.58	1.223	.984
13.36	4.70	1.591	.946
10.82	3.75	2.149	.877
8.280	2.92	2.838	.785
5.740	2.19	3.635	.665
3.200	1.63	4.300	.539
2.565	1.47	4.510	.498
1.930	1.35	4.591	.463
1.676	1.30	4.597	.446
1.422	1.28	4.546	.435
1.168	1.07	4.757	.373
.914	.932	4.771	.325
.660	.773	4.808	.271
.406	.603	4.806	.211
.279	.428	4.865	.151

TABLE 39 - Run 35

M_δ = 6.33 P_o = 15.12 atm

Re_θ = 8651 T_t = 547 °K

$\frac{T_w}{T_\delta}$ = 4.872 T_δ = 60.6 °K

C_q = 22.96 x 10^{-4} U_δ = 988 m/sec

Y	M	T/T_δ	U/U_δ
25.20	6.33	1.000	1.000
22.65	6.10	1.072	.998
20.11	5.79	1.179	.992
17.57	5.12	1.437	.968
15.03	4.30	1.847	.923
12.49	3.53	2.371	.858
9.947	2.85	2.968	.775
7.407	2.12	3.826	.655
4.867	1.65	4.377	.545
3.597	1.42	4.645	.482
2.327	1.17	4.884	.408
1.692	1.03	4.954	.363
1.057	.792	5.011	.280
.279	.334	4.966	.118

TABLE 40 - Run 36

M_δ = 6.27

Re_θ = 8969

$\frac{T_W}{T_\delta}$ = 4.838

$C_q = 26.47 \times 10^{-4}$

P_o = 15.15 atm

T_t = 546 °K

T_δ = 62.0 °K

U_δ = 986 m/sec

Y mm	M	T/T_δ	U/U_δ
25.40	6.27	1.000	1.000
22.86	5.94	1.000	1.000
20.32	5.34	1.196	.993
17.78	4.60	1.495	.947
15.24	3.85	1.918	.897
12.70	3.18	2.379	.825
10.16	2.56	2.942	.739
7.620	2.08	3.410	.647
5.080	1.62	3.921	.538
3.810	1.43	4.088	.487
2.540	1.19	4.323	.413
1.905	1.08	4.399	.381
1.270	.876	4.505	.313
1.016	.720	4.562	.259
.762	.515	4.622	.186
.635	.428	4.621	.155
.279	.313	4.472	.111

TABLE 41 - Run 37

M_δ = 6.37

Re_θ = 10640

$\frac{T_W}{T_\delta}$ = 4.887

$C_q = 26.44 \times 10^{-4}$

P_o = 15.12 atm

T_t = 547 °K

T_δ = 60.0 °K

U_δ = 990 m/sec

Y mm	M	T/T_δ	U/U_δ
32.31	6.37	1.000	1.000
29.77	6.32	1.016	999
27.23	6.16	1.062	.996
24.69	5.88	1.151	.991
22.15	5.37	1.339	.974
19.61	4.69	1.642	.942
17.07	4.08	1.978	.899
14.53	3.50	2.367	.846
11.99	2.90	2.895	.775
9.449	2.45	3.360	.702
6.909	2.00	3.830	.615
4.369	1.61	4.277	.522
3.099	1.41	4.489	.468
2.464	1.25	4.682	.423
1.829	1.18	4.667	.399
1.575	1.14	4.667	.385
1.321	.979	4.829	.338
1.067	.904	4.839	.312
.813	.803	4.891	.278
.559	.598	4.942	.209
.432	.554	4.904	.192
.305	.476	4.883	.165
.279			

TABLE 42 - Run 38

$M\delta = 6.53$ $P_o = 15.05$ atm

$Re\,\theta = 1713$ $T_t = 546\ ^oK$

$\frac{T_w}{T_\delta} = 5.582$ $T_\delta = 57.3\ ^oK$

$C_q = 0$ $U_\delta = 991$ m/sec

Y (mm)	M	T/T_δ	U/U_δ
19.36	6.53	1.000	1.000
18.09	6.53	1.000	1.000
16.82	6.53	1.000	1.000
15.54	6.53	1.000	1.000
14.28	6.54	.998	1.000
13.00	6.54	.998	1.000
11.74	6.54	1.000	1.000
10.46	6.53	1.004	1.001
9.195	6.50	1.013	1.002
7.925	6.41	1.041	1.001
6.655	6.19	1.110	.998
5.385	5.73	1.261	.986
4.750	5.43	1.379	.976
4.115	4.97	1.586	.959
3.480	4.52	1.839	.936
2.845	4.09	2.126	.914
2.210	3.71	2.444	.889
1.575	3.34	2.781	.853
1.321	3.16	2.891	.824
1.067	2.94	3.001	.779
.813	2.63	3.206	.720
.559	2.08	3.766	.618
.432	1.66	4.337	.528
.305	1.24	4.886	.419
.279	1.01	5.240	.355

TABLE 43 SUMMARY OF SKIN FRICTION AND HEAT TRANSFER DATA, $T_w/T_\infty = 7.6$

$T_w/T_\infty = 7.6$

RUN	X mm	M_∞	P_o atm	$Re_x \times 10^{-6}$	Re_θ	T_w/T_∞	$C_q \times 10^4$	$C_f \times 10^4$	C_f/C_{fo}	$2C_q/C_{fo}$	$St \times 10^4$	$\frac{St}{St_o}$
						$C_q = 0$	$T_w/T_\infty = 7.87$					
39	377.8	6.31	15.12	2.840	1323	7.614	0	19.54	1.000	0	28.3	1.000
40	428.6	6.45	15.05	3.429	1720	7.780	0	17.70	1.000	0	29.4	1.000
41	479.4	6.61	15.12	4.252	2200	8.080	0	15.74	1.000	0	23.3	1.000
42	530.2	6.62	15.08	4.803	2844	8.018	0	14.50	1.000	0	20.6	1.000
						$C_q = 8.68 \times 10^{-4}$	$T_w/T_\infty = 7.65$					
43	479.4	6.51	15.08	4.099	4541	7.650	8.68	11.20	.712	1.103	10.71	.460
						$C_q = 16.2 \times 10^{-4}$	$T_w/T_\infty = 7.65$					
44	479.4	6.57	15.08	4.514	6365	7.649	16.17	8.41	.534	2.055	5.18	.222
						$C_q = 24.4 \times 10^{-4}$	$T_w/T_\infty = 7.26$					
45	479.4	6.49	15.01	4.632	8928	7.259	24.42	6.06	.385	3.103	2.82	.121
						$C_q = 0$	$T_w/T_\infty = 7.81$					
46	479.4	6.43	20.01	4.897	2860	7.805	0	14.56	1.000	0	23.08	1.000

TABLE 44 SUMMARY OF BOUNDARY LAYER PARAMETERS, T_w/T_s = 7.6

T_w/T_s = 7.6

RUN	X mm	$Re_x \times 10^{-6}$	T_w/T	$C_q \times 10^4$	θ mm	δ^* mm	δ mm	Θ mm	Re_θ	δ^*/θ
				C_q = 0		T_w/T_s = 7.87				
39	377.8	2.840	7.614	0	.176	3.78	6.2		1324	21.48
40	428.7	3.429	7.780	0	.215	4.72	7.5		1720	21.95
41	479.4	4.252	8.080	0	.248	5.56	8.5		2200	22.42
42	530.2	4.803	8.018	0	.314	6.57	10.2		2844	20.92
				C_q = 8.68x10^{-4}		T_w/T_s = 7.65				
43	479.4	4.099	7.650	8.68	.531	8.45	15.0		4541	15.91
				C_q = 16.2x10^{-4}		T_w/T_s = 7.65				
44	479.4	4.514	7.649	16.17	.676	12.90	17.5		5788	19.08
				C_q = 24.4x10^{-4}		T_w/T_s = 7.26				
45	479.4	4.632	7.259	24.42	.924	17.42	23.0		8928	18.85
				C_q = 0		T_w/T_s = 7.81				
46	479.4	4.897	7.805	0	.280	5.24	8.7		2860	18.71

TABLE 45 - Run 39

M = 6.31 P_o = 15.12 atm

Re_θ = 1323 T_t = 549°K

$\frac{T_w}{T_\delta}$ = 7.614 T_δ = 61.3°K

C_q = 0 U_δ = 991. m/sec

Y (mm)	M	T/T_δ	U/U_δ
24.10	6.29	1.000	1.000
17.76	6.34	1.000	1.000
13.94	6.34	1.000	1.000
11.41	6.34	1.000	1.000
10.14	6.31	1.000	1.000
8.865	6.25	1.021	1.000
7.595	6.07	1.077	.998
6.325	5.75	1.191	.993
5.055	5.18	1.423	.978
4.420	4.83	1.600	.967
3.785	4.41	1.847	.950
2.515	3.66	2.452	.909
1.880	3.33	2.809	.884
1.499	3.05	3.143	.856
1.245	2.79	3.496	.826
.991	2.42	4.037	.771
.737	1.89	4.967	.668
.610	1.60	5.555	.596
.483	1.32	6.081	.515
.279	.827	6.942	.345

TABLE 46 - Run 40

M = 6.45 P_o = 15.05 atm

Re = 1720 T_t = 550°K

T_w/T = 7.780 T = 59.2°K

Cq = 0 U = 995 m/sec

Y (mm)	M	T/T	U/U
12.89	6.45	1.000	1.000
12.26	6.44	1.005	1.000
11.62	6.42	1.011	1.000
10.99	6.38	1.025	1.000
10.35	6.33	1.042	1.000
9.716	6.25	1.068	1.000
9.081	6.14	1.103	.999
8.446	5.98	1.156	.997
7.811	5.80	1.222	.994
7.176	5.58	1.308	.988
6.541	5.32	1.418	.981
5.906	5.04	1.551	.972
5.271	4.74	1.709	.961
4.636	4.44	1.892	.947
4.001	4.18	2.079	.933
3.366	3.90	2.307	.918
2.731	3.61	2.592	.900
2.096	3.32	2.911	.879
1.461	2.93	3.412	.849
1.207	2.66	3.807	.803
.953	2.28	4.398	.740
.699	1.71	5.457	.619
.572	1.42	6.036	.542
.445	1.21	6.462	.475
.318	.961	6.905	.391
.279	.761	7.285	.318

TABLE 47 - Run 41

M = 6.61 P_o = 15.12 atm

Re = 2200 T_t = 548°K

T_w/T = 8.080 T = 56.4°K

Cq = 0 U = 995 m/sec

Y (mm)	M	T/T	U/U
19.41	6.61	1.000	1.000
18.14	6.61	1.000	1.000
16.74	6.61	1.000	1.000
14.33	6.58	1.010	1.000
11.79	6.42	1.062	1.000
10.52	6.24	1.119	.999
9.246	5.95	1.221	.995
7.976	5.55	1.378	.985
6.706	5.06	1.601	.969
5.436	4.57	1.883	.948
4.166	4.06	2.244	.921
2.896	3.57	2.720	.891
2.261	3.29	3.048	.869
1.626	2.92	3.551	.833
1.372	2.71	3.843	.803
1.118	2.38	4.392	.754
.864	1.91	5.259	.663
.737	1.66	5.775	.604
.610	1.38	6.395	.527
.483	1.09	7.007	.436
.356	.972	7.307	.398
.279	.774	7.512	.321

TABLE 48 - Run 42

M_δ = 6.62 P_o = 15.08 atms

Re_θ = 2844 T_t = 548 °K

$\frac{T_w}{T_\delta}$ = 8.018 T_δ = 56.2 °K

C_q = 0 U_δ = 995 m/sec

Y (mm)	M	T/T_δ	U/U_δ
23.90	6.62	1.000	1.000
17.55	6.53	1.024	.999
13.74	6.36	1.077	.998
12.47	6.24	1.119	.996
11.20	6.03	1.191	.995
9.931	5.75	1.298	.989
8.661	5.39	1.449	.980
7.391	4.98	1.647	.966
6.121	4.55	1.891	.944
4.851	4.11	2.196	.921
4.216	3.91	2.369	.908
3.581	3.67	2.590	.892
2.946	3.43	2.843	.874
2.311	3.19	3.136	.854
1.676	2.85	3.631	.820
1.041	2.20	4.686	.721
.787	1.71	5.662	.615
.660	1.46	6.187	.548
.533	1.09	7.002	.436
.406	.975	7.151	.394
.279	.763	7.488	.315

TABLE 49 - Run 43

$M_\delta = 6.51$ $P_o = 15.08$ atm

$Re_\theta = 4541$ $T_c = 551$ °K

$\frac{T_w}{T_\delta} = 7.650$ $T_\delta = 58.4$ °K

$C_q = 8.68 \times 10^{-4}$ $U_\delta = 1007$ m/sec

Y (mm)	M	T/T_δ	U/U_δ
25.42	6.62	1.000	1.000
22.88	6.63	1.000	1.000
20.34	6.62	1.000	1.000
17.81	6.57	1.000	1.000
15.26	6.20	1.098	.990
12.72	5.58	1.322	.977
11.46	5.18	1.494	.964
10.18	4.78	1.696	.947
8.915	4.38	1.937	.927
7.645	3.98	2.214	.901
6.375	3.60	2.534	.872
5.105	3.22	2.915	.838
4.470	3.05	3.111	.820
3.835	2.87	3.337	.799
3.200	2.68	3.614	.775
2.565	2.46	3.951	.745
1.930	2.18	4.430	.700
1.295	1.79	5.156	.618
.660	1.11	6.511	.430
.533	.950	6.797	.377
.406	.748	7.140	.304
.279	.628	7.280	.258

TABLE 50 - Run 44

$M_\delta = 6.57$ $P_o = 15.08$ atm

$Re_\theta = 6365$ $T_c = 549$ °K

$\frac{T_w}{T_\delta} = 7.649$ $T_\delta = 57.0$ °K

$C_q = 16.17 \times 10^{-4}$ $U_\delta = 994$ m/sec

Y mm	M	T/T_δ	U/U_δ
27.94	6.57	1.000	1.000
25.40	6.53	1.012	1.000
22.86	6.44	1.040	1.000
20.32	6.19	1.127	1.000
17.78	5.68	1.315	.991
16.51	5.32	1.465	.980
15.24	4.94	1.618	.957
12.70	4.17	2.116	.923
11.43	3.80	2.409	.896
10.16	3.42	2.761	.864
8.890	3.08	3.129	.829
7.620	2.81	3.454	.795
6.350	2.53	3.846	.754
5.080	2.25	4.267	.708
3.810	1.94	4.824	.649
2.540	1.64	5.411	.580
1.905	1.46	5.747	.534
1.270	1.16	6.359	.444
1.016	1.04	6.564	.407
.762	.903	6.807	.359
.508	.675	7.184	.275
.381	.568	7.317	.234
.279	.428	7.485	.176

TABLE 51 - Run 45

$M_\delta = 6.49$

$Re_\theta = 8928$

$\frac{T_w}{T_\delta} = 7.259$

$C_q = 24.42 \times 10^{-4}$

$P_o = 15.01$ atm

$T_t = 548$ °K

$T_\delta = 58.2$ °K

$U_\delta = 992$ m/sec

Y (mm)	M	T/T$_\delta$	U/U$_\delta$
35.54	6.49	1.000	1.000
33.00	6.49	1.000	1.000
30.46	6.45	1.010	.999
27.92	6.35	1.041	.999
25.38	6.12	1.119	.998
22.84	5.58	1.315	.987
20.30	4.92	1.618	.964
17.76	4.14	2.087	.921
15.22	3.41	2.697	.862
12.68	2.83	3.332	.795
10.14	2.37	3.933	.724
7.595	1.92	4.633	.637
5.055	1.43	5.519	.519
3.785	1.34	5.656	.489
2.515	1.11	6.072	.421
1.880	.963	6.331	.374
1.245	.796	6.612	.316
.991	.632	6.881	.256
.483	.520	7.016	.212
.279	.329	7.216	.136

TABLE 52 - Run 46

$M_\delta = 6.43$

$Re_\theta = 2860$

$\frac{T_w}{T_\delta} = 7.805$

$C_q = 0$

$P_o = 20.01$ atm

$T_t = 548$ °K

$T_\delta = 59.1$ °K

$U_\delta = 992$ m/sec

Y (mm)	M	T/T$_\delta$	U/U$_\delta$
23.39	6.42	1.000	1.000
17.04	6.43	1.000	1.000
15.77	6.43	1.000	1.000
13.23	6.40	1.009	.999
11.96	6.34	1.030	.999
10.69	6.19	1.073	.997
9.423	5.95	1.156	.995
8.153	5.59	1.288	.986
6.883	5.14	1.481	.971
5.613	4.66	1.727	.951
4.343	4.16	2.043	.923
3.073	3.63	2.477	.889
1.803	3.04	3.159	.841
1.168	2.62	3.784	.792
1.041	2.49	3.993	.772
.914	2.30	4.290	.742
.787	2.06	4.725	.695
.660	1.76	5.310	.629
.533	1.40	6.049	.536
.406	1.09	6.677	.439
.279	.868	7.061	.358

TABLE 53 SUMMARY OF SKIN FRICTION AND HEAT TRANSFER DATA, T_w/T_δ = 7.6

T_w/T_δ=7.6

RUN	X mm	M_δ	P_o atm	Re_xx10-6	Re_θ	T_w/T_δ	c_qx10^4	c_fx10^4	c_f/c_{fo}	$2C_q/C_{fo}$	Stx10^4	$\frac{St}{St_o}$
47	530.2	6.34	38.07	9.70	4897	7.06	0	9.92	1.000	0	8.3	1.000
48	530.2	6.46	38.07	10.76	6824	7.19	3.70	8.35	.841	.746	5.83	.702
49	530.2	6.47	38.07	10.84	8753	7.01	7.25	7.6	.767	1.464	4.49	.541
50	530.2	6.52	38.07	11.03	11737	6.87	10.13	6.25	.630	2.040	3.64	.439

TABLE 54 SUMMARY OF BOUNDARY LAYER PARAMETERS, T_w/T_δ = 7.6

T_w/T_δ=7.6

RUN	X	$Re_x x10^{-6}$	T_w/T_δ	$c_q x10^4$	θ	δ^*	δ	$\mathcal{E}$	Re_θ	δ^*/θ
47	530.2	9.70	7.06	0	.265	4.66	8.0	.150	4897	17.6
48	530.2	10.76	7.19	3.70	.336	6.26	9.5	.640	6824	16.91
49	532.0	10.84	7.01	7.25	.428	7.80	11.0	1.36	8753	18.22
50	530.2	11.03	6.87	10.13	.564	9.80	14.2	2.74	11737	17.38

TABLE 55 - Run 47

M = 6.34 P_o = 33.07 atm

Re = 4897 T_t = 550°K

T_w/T = 7.06 T = 61.0°K

C_q = 0 U = 992.0 m/sec

Y (mm)	M	T/T	U/U
21.22	6.34	1.000	1.000
18.68	6.33	1.003	1.000
16.14	6.33	1.003	1.000
13.60	6.32	1.006	1.000
11.06	6.25	1.025	.999
9.792	6.17	1.054	.999
8.522	5.96	1.123	.997
7.252	5.57	1.262	.988
6.617	5.30	1.371	.980
5.982	5.01	1.497	.968
4.712	4.42	1.810	.939
4.077	4.12	1.999	.920
3.442	3.80	2.240	.898
2.807	3.52	2.486	.875
2.172	3.23	2.777	.850
1.537	2.94	3.131	.822
.902	2.34	4.028	.742
.648	1.94	4.660	.682
.521	1.70	5.066	.643
.394	1.38	5.607	.517
.267	1.08	6.114	.421
.191	1.04	6.103	.403

TABLE 56 - Run 48

M = 6.46 P = 38.07 atm

Re = 6824 T_t = 548 K

$\frac{T_w}{T}$ = 7.19 T = 58.7 K

$C_q = 3.70 \times 10^{-4}$ U = 992 m/sec

Y (mm)	M	T/T	U/U
26.25	6.46	1.000	1.000
23.71	6.45	1.003	1.000
21.17	6.43	1.007	1.000
18.63	6.42	1.010	1.000
16.09	6.42	1.014	1.000
13.55	6.40	1.034	1.000
11.01	6.41	1.112	1.000
10.38	5.98	1.162	.998
9.741	5.80	1.226	.994
9.106	5.58	1.305	.988
8.471	5.34	1.402	.980
7.836	5.07	1.521	.969
7.201	4.81	1.649	.957
6.566	4.55	1.797	.944
5.931	4.25	1.978	.926
5.296	3.97	2.176	.908
4.661	3.68	2.409	.885
4.026	3.35	2.716	.856
3.391	3.08	3.015	.827
2.756	2.85	3.285	.800
2.121	2.62	3.600	.770
1.486	2.34	4.070	.730
.851	1.84	4.951	.634
.597	1.51	5.496	.549
.470	1.31	5.848	.492
.343	1.04	6.302	.406
.292	.959	6.441	.377
.191	.911	6.410	.357

TABLE 57 - Run 49

M = 6.47 P = 38.77 atm

Re = 8753 T_t = 549 K

$\frac{Tw}{T}$ = 7.01 T = 58.6 K

C_q = 7.25×10^{-4} U = 993 m/sec

Y (mm)	M	T/T	U/U
28.79	6.47	1.000	1.000
26.25	6.46	1.003	1.000
23.71	6.45	1.008	1.000
21.17	6.44	1.010	1.000
18.63	6.44	1.010	1.000
16.09	6.38	1.032	1.002
13.55	6.20	1.095	1.003
12.28	5.94	1.187	.999
11.01	5.54	1.335	.989
10.38	5.28	1.440	.979
9.741	5.06	1.538	.970
9.106	4.78	1.679	.957
8.471	4.56	1.799	.945
7.201	4.06	2.117	.913
5.931	3.57	2.507	.873
4.661	3.10	2.981	.826
3.391	2.67	3.488	.771
2.756	2.46	3.780	.740
2.121	2.25	4.122	.706
1.486	2.00	4.559	.659
.851	1.61	5.236	.569
.597	1.37	5.589	.502
.343	.943	6.305	.366
.267	.863	6.389	.337
.191	.768	6.492	.302

TABLE 58 - Run 50

M = 6.52 P = 38.77 atm

Re = 11,737 T_t = 553 K

$\frac{Tw}{T}$ = 6.87 T = 58.2 K

C_q = 10.13×10^{-4} U = 997 m/sec

Y (mm)	M	T/T	U/U
28.77	6.52	1.000	1.000
23.69	6.49	1.009	1.000
18.61	6.43	1.031	1.000
16.07	6.24	1.097	.999
13.53	5.64	1.299	.985
12.26	5.16	1.499	.973
10.99	4.69	1.741	.958
9.716	4.22	2.015	.920
8.446	3.84	2.289	.892
7.176	3.27	2.818	.843
5.906	2.89	3.234	.797
4.636	2.52	3.676	.741
3.366	2.17	4.193	.682
2.731	2.01	4.459	.652
2.096	1.83	4.786	.615
1.461	1.62	5.186	.564
.826	1.34	5.617	.488
.572	1.15	5.907	.428
.445	.964	6.181	.368
.318	.832	6.337	.317
.191	.693	6.457	.270

TABLE 59 SUMMARY OF SKIN FRICTION AND HEAT TRANSFER DATA, $T_w/T_\delta = 4.1$

$T_w/T_\delta = 4.1$

RUN	X mm	M_δ	P_o atm	$Re_x \times 10^{-6}$	Re	T_w/T_δ	$C_q \times 10^4$	$C_f \times 10^4$	C_f/C_{fo}	$2C_q/C_{fo}$	$St \times 10^4$	$\frac{St}{St_o}$
					$C_q = 0$		$T_w/T_\delta = 4.70$					
51	428.6	6.50	38.07	8.529	3841	4.665	0	6.26	1.000	0	4.61	1.000
52	479.4	6.49	38.07	9.260	4557	4.735	0	6.97	1.000	0	4.47	1.000
53	530.2	6.37	38.01	10.13	5997	4.700	0	6.81	1.000	0	4.00	1.000
					$C_q = 0$		$T_w/T_\delta = 4.32$					
54	530.2	6.34	35.01	8.98	5218	4.32	0	7.73	1.000	0	4.64	1.000
					$C_q = 4.12 \times 10^{-4}$		$T_w/T_\delta = 4.41$					
55	530.2	6.50	35.01	9.57	7816	4.41	4.12	6.41	.83	1.066	2.95	.636
					$C_q = 8.17 \times 10^{-4}$		$T_w/T_\delta = 4.37$					
56	530.2	6.45	35.01	9.41	10011	4.37	8.17	5.30	.686	2.114	2.44	.526
					$C_q = 12.1 \times 10^{-4}$		$T_w/T_\delta = 4.35$					
57	530.2	6.47	35.01	9.89	12775	4.35	12.1	4.23	.547	3.123	2.14	.461

TABLE 60 SUMMARY OF BOUNDARY LAYER PARAMETERS, T_w/T_δ = 4.1

T_w/T_δ=4.1

RUN	X	Re_xx10	T_w/T_δ	C_qx10^{-4}	θ	δ^*	δ	Θ	Re_θ	$\frac{\delta}{q}$
				C_q=0	T_w/T_δ=4.32					
51	428.6	8.529	4.665	0	.193	2.78	5.20	.248	3841	14.40
52	479.4	9.26	4.735	0	.236	3.51	5.85	.284	4557	14.88
53	530.2	10.13	4.700	0	.313	4.70	7.70	.408	5997	15.01
				C_q=0	T_w/T_δ=4.32					
54	530.2	8.98	4.32	0	.308	4.63	7.8		5218	15.02
				C_q=4.12x10^{-4}	T_w/T_δ=4.41					
55	530.2	9.57	4.41	4.12	.433	6.52	10.7		7816	15.06
				C_q=8.17x10^{-4}	T_w/T_δ=4.37					
56	530.2	9.41	4.37	8.17	.564	7.64			10011	13.55
				C_q=12.1x10^{-4}	T_w/T_δ=4.35					
57	530.2	9.89	4.35	12.1	.685	9.22	14.8		12775	13.46

TABLE 61 - Run 51

M = 6.50 P = 38.07 atm

Re = 3841 T_t = 550 K

$\frac{T_w}{T}$ = 4.665 T = 58.1 K

C_q = 0 U = 994 m/sec

Y (mm)	M	T/T	U/U
10.77	6.50	1.000	1.000
9.499	6.50	1.002	1.000
8.864	6.49	1.004	1.000
8.229	6.49	1.005	1.000
7.584	6.47	1.009	.999
6.959	6.43	1.020	.998
6.324	6.34	1.044	.996
5.689	6.21	1.085	.994
5.054	5.94	1.176	.991
4.419	5.66	1.276	.983
3.784	5.21	1.464	.969
3.149	4.72	1.695	.944
2.631	4.29	1.945	.920
2.133	3.89	2.221	.891
1.879	3.69	2.377	.875
1.625	3.51	2.539	.858
1.371	3.33	2.705	.841
1.117	3.14	2.875	.819
.863	2.95	3.063	.793
.736	2.82	3.159	.771
.609	2.53	3.495	.726
.482	2.06	4.040	.635
.431	1.85	4.296	.589
.406	1.78	4.339	.553
.304	1.74	4.128	.542

TABLE 62 - Run 52

M = 6.49 P_o = 38.07 atm

Re = 4557 T_t = 550°K

T_w/T = 4.735 T = 58.6°K

C_q = 0 U = 996 m/sec

Y (mm)	M	T/T	U/U
23.62	6.49	1.000	1.000
21.08	6.49	1.000	1.000
18.54	6.48	1.003	1.000
16.00	6.48	1.002	.999
13.46	6.48	1.002	.999
10.92	6.47	1.005	.999
9.650	6.45	1.013	1.000
8.380	6.40	1.027	1.000
7.745	6.35	1.042	.999
7.110	6.26	1.071	.997
6.475	6.09	1.124	.994
5.840	5.86	1.199	.989
5.205	5.56	1.307	.979
4.570	5.18	1.462	.965
3.935	4.78	1.638	.943
3.554	4.52	1.778	.929
3.300	4.38	1.856	.918
2.919	4.14	1.997	.901
2.665	4.01	2.082	.891
2.284	3.76	2.258	.871
2.030	3.58	2.399	.855
1.776	3.64	2.321	.855
1.552	3.25	2.707	.823
1.268	3.09	2.882	.807
1.014	2.93	3.047	.787
.760	2.74	3.194	.753
.557	2.37	3.496	.682
.532	2.30	3.570	.669
.506	2.24	3.656	.652
.430	1.90	4.037	.588
.379	1.72	4.232	.546

TABLE 63 - Run 53

M = 6.37 | P_o = 38.01 atm

Re = 5997 | T_t = 549°K

$\frac{T_w}{T}$ = 4.700 | T = 60.2°K

C_q = 0 | U = 991 m/sec

Y (mm)	M	T/T	U/U
26.75	6.37	1.000	1.000
24.21	6.36	1.002	.999
21.67	6.34	1.008	.999
19.13	6.33	1.012	.998
16.59	6.31	1.018	.998
14.05	6.30	1.021	.998
11.51	6.24	1.038	.998
10.24	6.21	1.052	.999
8.972	6.11	1.083	.998
7.702	5.83	1.174	.990
6.432	5.34	1.348	.973
5.162	4.74	1.609	.943
3.892	4.12	1.951	.902
3.257	3.79	2.174	.876
2.622	3.44	2.442	.843
1.987	3.13	2.722	.810
1.352	2.79	3.076	.769
1.098	2.65	3.224	.747
.844	2.52	3.330	.720
.590	2.21	3.610	.660
.463	1.90	3.953	.594
.336	1.45	4.524	.484

TABLE 64 - Run 54

M = 6.34 | P_o = 35.01 atm

Re = 5218 | T_t = 548.5°K

$\frac{T_w}{T}$ = 4.32 | T = 60.7°K

C_q = 0 | U = 990 m/sec

Y (mm)	M	T/T	U/U
29.74	6.34	1.000	1.000
27.20	6.34	1.000	1.000
24.66	6.34	1.000	1.000
22.12	6.33	1.003	1.000
19.58	6.33	1.005	1.000
17.04	6.31	1.011	1.000
14.50	6.31	1.011	1.000
11.96	6.25	1.030	1.000
10.69	6.20	1.044	.999
9.423	6.12	1.070	.998
8.153	5.89	1.148	.995
6.883	5.45	1.30	.981
6.248	5.20	1.42	.977
5.613	4.92	1.52	.958
4.978	4.62	1.67	.942
4.343	4.31	1.84	.922
3.708	4.02	2.01	.899
3.073	3.70	2.23	.872
2.438	3.38	2.48	.841
1.803	3.06	2.78	.804
1.549	2.92	2.91	.786
1.295	2.79	3.06	.769
1.041	2.65	3.20	.747
.787	2.51	3.29	.718
.660	2.38	3.37	.688
.533	2.17	3.50	.641
.406	1.80	3.88	.558
.279	1.27	4.42	.422

TABLE 65 - Run 55

$M = 6.50$ $P_o = 35.01$ atm

$Re = 7816$ $T_t = 549.5^{\circ}K$

$\frac{T_w}{T} = 4.41$ $T = 58.0^{\circ}K$

$C_q = 4.12 \times 10^{-4}$ $U = 994$ m/sec

Y (mm)	M	T/T	U/U
29.84	6.50	1.000	1.000
27.31	6.51	1.000	1.000
24.76	6.48	1.007	1.000
22.22	6.45	1.016	1.000
19.68	6.44	1.020	1.000
17.14	6.44	1.021	1.000
14.61	6.40	1.032	1.000
12.06	6.21	1.092	.997
10.80	6.00	1.160	.994
9.525	5.62	1.30	.983
8.255	5.15	1.49	.965
6.985	4.65	1.73	.940
5.715	4.13	2.03	.904
4.445	3.60	2.40	.858
3.810	3.34	2.62	.830
3.175	3.09	2.83	.799
2.540	2.82	3.10	.764
1.905	2.58	3.36	.726
1.651	2.45	3.51	.705
1.397	2.37	3.58	.691
1.143	2.26	3.72	.670
.889	2.11	3.86	.636
.762	2.01	3.90	.610
.635	1.84	4.00	.567
.508	1.58	4.17	.496
.279	1.14	4.30	.363

TABLE 66 - Run 56

$M = 6.45$ $P_o = 35.01$ atm

$Re = 10,011$ $T_t = 548.5^{\circ}K$

$\frac{T_w}{T} = 4.38$ $T = 59.2^{\circ}K$

$C_q = 8.17 \times 10^{-4}$ $U = 995.0$ m/sec

Y (mm)	M	T/T	U/U
29.74	6.45	1.000	1.000
27.20	6.44	1.004	1.000
24.66	6.43	1.005	1.000
22.12	6.42	1.007	1.000
19.58	6.41	1.011	1.000
17.04	6.40	1.015	1.000
14.50	6.23	1.065	.997
13.23	6.06	1.12	.995
11.96	5.76	1.22	.987
10.69	5.37	1.37	.974
9.423	4.92	1.56	.953
8.153	4.48	1.78	.926
6.883	4.02	2.04	.891
5.613	3.56	2.35	.847
4.978	3.33	2.52	.822
4.343	3.12	2.70	.795
3.708	2.92	2.87	.768
3.073	2.67	3.12	.730
2.438	2.48	3.28	.698
1.803	2.26	3.51	.656
1.549	2.18	3.60	.642
1.295	2.09	3.69	.623
1.041	2.01	3.72	.602
.914	1.93	3.77	.582
.787	1.85	3.77	.558
.660	1.76	3.77	.529
.533	1.63	3.79	.493
.432	1.43	3.94	.441
.279	1.12	4.10	.351

TABLE 67 - Run 57

M = 6.47

Re = 12,775

$\frac{T_w}{T}$ = 4.35

$C_q = 12.1 \times 10^{-4}$

P_o = 35.01 atm

T_t = 549°K

T = 58.6°K

U = 993 m/sec

Y (mm)	M	T/T	U/U
29.95	6.47	1.000	1.000
27.41	6.46	1.003	1.000
24.87	6.44	1.009	1.000
22.33	6.43	1.009	.999
19.79	6.42	1.012	.999
17.25	6.32	1.044	.998
15.98	6.18	1.085	.996
14.71	5.95	1.162	.991
13.44	5.63	1.277	.983
12.17	5.31	1.394	.970
10.90	4.81	1.613	.945
9.627	4.34	1.862	.915
8.357	3.91	2.12	.880
7.087	3.48	2.43	.837
5.817	3.06	2.77	.787
4.547	2.67	3.12	.729
3.277	2.30	3.48	.663
2.642	2.13	3.64	.628
2.007	1.92	3.86	.584
1.753	1.85	3.93	.568
1.499	1.76	4.02	.546
1.245	1.70	4.05	.529
.991	1.60	4.13	.501
.864	1.52	4.17	.479
.737	1.43	4.20	.452
.610	1.33	4.21	.424
.483	1.18	4.29	.377
.279	.908	4.33	.292

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13 ABSTRACT

A tabulation of turbulent boundary layer data obtained under conditions of heat and mass transfer at a Mach number of 6.7 is presented. The report supplements the treatise given in NOLTR 64-99. A brief description of the model and test procedure is included.

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